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(54) Title: PROCESS FOR THE OXIDATION OF DI-, TRI-, OLIGO- AND POLYSACCHARIDES INTO POLYHYDROXYCARBOXYLIC ACIDS (57) Abstract <p>A process is provided for preparing polyhydroxycarboxylic acids by the selective oxidation of di-, tri-, oligo- and polysaccharides in an alkaline medium using an oxygenous gas in the presence of Pd on a carrier as catalyst and Bi as promoter at a Pd concentration in the reaction mixture of at least 40 mg/l and a molar ratio of Bi to Pd in the range of from 1:5 to 1:40, in which process towards the end of the reaction, as soon as a strong increase is observed in the oxygen concentration in the liquid phase, the oxygen supply is reduced until it is not more than 20 ppm. In this manner virtually all of the polysaccharide added beforehand is converted into the desired end product without an unacceptably high concentration of Bi in the end product.</p>		

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PROCESS FOR THE OXIDATION OF DI-, TRI-, OLIGO- AND POLY-SACCHARIDES INTO POLYHYDROXYCARBOXYLIC ACIDS

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The invention relates to the preparation of polyhydroxycarboxylic acids by the selective oxidation of di-, tri-, oligo- and polysaccharides in an alkaline medium using an oxygenous gas in the presence of Pd on a carrier as catalyst and Bi as promoter.

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Such a process is known from US 4,985,553, and a further working-out of the oxidation of lactose can be found in an article by H. Hendriks et al. in Carbohydrate Research 204 (1990), 121-129.

15 A drawback to the process described in said publications is that although the percentage of polysaccharides which can be converted in this manner is over 90%, notably in the oxidation of lactose it fails to advance beyond 95%. In Example V of the aforementioned patent publication a conversion rate of 91% is listed for the oxidation of lactose. Such a mixture of
20 polysaccharide or aldose and salt of the corresponding carboxylic acid is hard to purify on a commercial scale. Moreover, the product was found to be too badly contaminated with residual catalyst. A further drawback to the process claimed in US 4,985,553 is the laborious catalyst preparation. It involves mixing a solution of a Bi compound, with vigorous stirring, with an
25 aqueous suspension of the Pd deposited onto a carrier. The whole is made alkaline by adding a base, followed by reduction of the Bi compound with formalin, sodium formate, sodium boron hydride, hypophosphorous acid, hydrazine, glucose, or other reducing sugars. The catalyst thus reduced is filtered, washed, and dried.

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The invention now provides a process which largely obviates the aforementioned drawbacks.

5 The invention consists in that in a process of the known type mentioned in the opening paragraph the reaction is carried out at a Pd concentration in the reaction mixture of at least 40 mg/l and a molar ratio of Bi to Pd in the range of 1:5 to 1:40, in which process towards the end of the reaction, as soon as a strong increase is observed in the oxygen concentration in the liquid phase, the oxygen supply is reduced until it is not more than 20 ppm.

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Surprisingly, it has been found that when before the end of the reaction a reduction of the supply of oxygen ensures that the oxygen concentration in the liquid phase cannot exceed 20 ppm, the catalyst is deactivated hardly if at all. In consequence, virtually all of the polysaccharide added beforehand is converted into the desired end product within a reasonable period of time. Deactivation of the catalyst leads to an unacceptably long reaction time and incomplete conversion of the starting material. For instance, in Example V of US 4,985,553 after a reaction time of 1hr20 only 91% of the lactose has been converted.

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To obtain a satisfactory result it is also essential to have a Pd concentration in the reaction mixture of at least 40 mg/l and a molar ratio of Bi to Pd which stays within the claimed range. A molar ratio of Bi to Pd >1:5 results in an unacceptably high concentration of Bi in the end product and an increased reaction time. A molar ratio of Bi to Pd <1:40, on the other hand, produces incomplete conversion of the polysaccharide employed.

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According to the present invention, preference is given to a process where before the end of the reaction a reduction of the supply of oxygen ensures that the oxygen concentration in the liquid phase does not exceed 10 ppm.

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Optimum results are attained in this case when the reduction of the oxygen supply is adjusted such that the oxygen concentration in the liquid phase cannot exceed 5 ppm, and preferably cannot exceed 1 ppm.

- 5 Examples of polysaccharides which can be oxidized using the process according to the invention are lactose, maltose, isomaltose, cellobiose, xylobiose, and mannobiose. Optimum results so far have been attained using lactose and maltose.
- 10 Oxygen can be passed into the reaction mixture in many different ways. So far, favorable results have been attained dosing oxygen, air or nitrogen diluted oxygen at the start of the reaction. During the reaction the oxygen concentration in the liquid phase is continuously measured with a sensor. One way of adjusting the oxygen concentration in the liquid reaction
- 15 mixture is by controlling the rate of stirring of the preferably employed turbo stirrer. The polysaccharide conversion is easily calculated from the amount of lye needing to be added to maintain a constant pH level. By varying the rate of stirring in the reaction mixture the oxygen concentration in the reaction mixture can be continuously adjusted, which adjustment can be
- 20 refined further by greater dilution of the oxygenous gas with nitrogen.

A major advantage of the process now proposed is that the promoter need not first be incorporated into the catalyst via a laborious process, but can be added to the reaction mixture separately. As regards the Pd,

25 advantageous use may be made of various commercially available embodiments where the Pd is deposited on a carrier of activated carbon. The Bi may be added with advantage in the form of an aqueous solution of $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$. Optimum results in that case are obtained with a [Pd] of 100 mg/l and a [Bi] of 20 mg/l. Alternatively, the Bi may be added in the

30 form of Bi_2O_3 .

- One important advantage of the option of adding the Bi separately is that complicated catalyst preparation may be dispensed with. A further advantage of the process according to the present invention is that there is no need to regenerate the catalyst after every cycle. For, surprisingly it has
- 5 been found that the catalyst can be re-used many times in a row without any noticeable loss of activity if on conclusion of the reaction the reaction mixture is heated for 1 to 30 minutes, preferably for 5 to 15 minutes at a temperature in the range of 50° to 90°C, preferably in the range of 65° to 85°C, prior to being filtered off at that temperature. The filtered catalyst is
- 10 immediately ready for use in a new oxidation cycle, while the filtrate can be refined further, e.g., by freeze-drying. If there is no heating at the end of each oxidation cycle, a reaction time increasing with every cycle and an increased loss of Pd should be taken into account.
- 15 The temperature at which the reaction can be carried out to favorable effect ranges from 20° to 90°C, with preference being given to a temperature ranging from 30° to 70°C, optimum results so far having been attained at a temperature ranging from 35° to 55°C.
- 20 The reaction is commonly carried out in such a way that first the catalyst is added beforehand to a 5 to 60 wt.% aqueous solution of a polysaccharide, followed by the introduction, with vigorous stirring, of an oxygenous gas and the simultaneous charging of an alkaline reacting substance to neutralize the formed carboxylic acid, the pH being kept at a value in the
- 25 range of 7.5 to 11, preferably in the range of 8 to 10. The neutralizing agent used may be sodium hydroxide, potassium hydroxide, calcium hydroxide, lithium hydroxide, magnesium hydroxide, or a carbonate such as sodium carbonate, or else zinc or manganese carbonate, or an amine such as triethyl amine.

The invention will be elucidated with reference to the following examples, which are for illustrative purposes only and in no way seek to limit the scope of the invention.

5 Example 1

In a 1 l glass reactor with a double jacket, equipped with a turbo stirrer, an oxygen sensor, and a pHstat, 5.52 g of Pd/C catalyst (5.2% of Pd, 63.7% of water, Johnson Mathey) and 57 mg of bismuth subnitrate pentahydrate
10 were suspended in 100 g of water and added to a solution obtained by heating 92.9 g of α -lactose•H₂O (97%, Aldrich, 0.25 mole) and 307 g of water.

The reaction was carried out at 40°C in an air atmosphere at standard
15 pressure, with the air from the gas phase of the reactor being contacted with the reaction mixture through vigorous stirring. At the same time the pH was kept at 9 by the corresponding addition of 20%-caustic soda. To keep the oxygen content in the gas phase at a constant level, an air stream was passed through the gas phase during the reaction. As soon as 98% of the
20 theoretical amount of caustic soda had been used up, the oxygen concentration in the solution began to increase. For that reason the oxygen supply to the reaction mixture was reduced by lowering the rotational speed of the stirrer, such that the oxygen concentration remained below 1 ppm.

25 After 76 minutes 100% of the computed caustic soda had been added, the reaction came practically to a stop, and was concluded. The reaction solution was separated from the catalyst by filtration and freeze-dried. Obtained were 104.9 g of a white solid which according to ¹³C NMR analysis consisted of pure sodium lactobionate. The sodium lactobionate
30 content was determined to be 98.5% (via ion exchange and titration of the

free acid). By HPLC analysis it was determined that 0.5% of lactose remained in the product, which corresponds to a conversion of 99.4%. Moreover, catalyst traces in the product were subjected to atomic absorption analysis: Bi <0.1 ppm, and Pd 0.3 ppm.

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Example 2

Example 1 was repeated, except that in the gas phase of the reactor instead of air pure oxygen was used, which was introduced via a gas
10 burette at standard pressure in accordance with consumption. At an NaOH consumption of 90% of the calculated amount the oxygen supply of the gas phase in the reaction mixture was reduced by lowering the rotational speed of the stirrer, such that the oxygen concentration in the solution was kept below 1 ppm. The reaction was concluded after 26 minutes at a caustic
15 soda addition of 100% of theory. Product analyses: sodium lactobionate (98.4% of theory); lactose 0.4%, Bi <0.1 ppm, and Pd 0.5 ppm.

Example 3 (Comparative Example)

20 The process of Example 2 was repeated, except that the rotational speed of the stirrer was not lowered at the end. After 30 minutes the NaOH addition came to a stop at 92% of the theoretical amount. The product was contaminated with 9% of unconverted lactose.

25 Example 4

The process of Example 1 was repeated, except that on conclusion of the reaction after 76 minutes the rotational speed of the stirrer was lowered to 150 rpm and the reaction mixture was heated for 10 minutes at 80°C. Next,
30 at the same temperature still, the reaction solution was removed from the

reactor through a filter candle. The catalyst staying behind in the reactor was used straight-away for a second cycle. This involved only the addition of a solution obtained by heating 92.9 g of lactose and 400 g of water, and bringing the suspension to reaction with air as in Example 1. In this way 11
5 reaction cycles in succession were carried out with the same catalyst. In the 11th cycle at a caustic soda addition of 96% of theory (increase in the oxygen concentration to 1 ppm) the rotational speed of the stirrer was adjusted, such that the oxygen concentration in the reaction mixture was kept below 1 ppm. After 79 minutes 100% of the calculated amount of
10 caustic soda had been added, the reaction came practically to a stop, and was concluded.

The products from the 11 cycles were each freeze-dried and analyzed. All contained >98% sodium lactobionate and 0.1 ppm Bi as well as < 0.05 ppm
15 Pd.

Example 5

The process of Example 4 was repeated, except that the reaction mixture
20 was not subjected to further heating after the reaction but immediately filtered through the filter candle at 40°C. In this way also 10 reaction cycles were carried out, with the reaction time increasing with each cycle. In the 10th cycle the oxygen concentration rose to 1 ppm already at a caustic soda consumption of 87% and was adjusted by means of the turbo stirrer.
25 The reaction time during this cycle was 94 minutes as compared with 76 minutes for the 1st cycle.

A further reaction cycle was carried through, with, in contrast to the first 10 cycles, an additional 15 mg of bismuth subnitrate being added. In this process the oxygen concentration rose to 1 ppm at a caustic soda
30 consumption of 98% of theory, and the rotational speed of the stirrer was

lowered accordingly. The reaction period until 100% caustic soda consumption this time was 78 minutes. The products of all reaction cycles had a sodium lactobionate content >98%, the lactose content was <0.6%, and the metal concentration was <0.1 ppm for Bi and 0.1-1 ppm for Pd.

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Example 6 (Comparative Example with a higher share of Bi, in accordance with "Carb. Res." 204 (1990), 121-129))

The process of Example 2 was carried out, except that this time only 1.38g
10 of the Pd-catalyst were employed as catalyst (the molar ratio Pd:Bi was 1:1.9). Moreover, a reaction temperature of 50°C was selected. The reaction did not start up until the reactor had been flushed with nitrogen repeatedly, followed by replacement of the nitrogen with oxygen. Once a caustic soda addition of 85% of theory was reached, the oxygen
15 concentration rose and was kept at <1 ppm by lowering the rotational speed of the stirrer. After 41 minutes the conversion was practically complete. The product in any case contained 62 ppm Bi and 0.2 ppm Pd.

Example 7

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As described in Example 2, instead of lactose were used 90.1 g of a commercial starch hydrolysate ("Fermentose," 70% maltose, 20% maltotriose). The reaction was carried out at 50°C. At a caustic soda addition of 210 mmoles the oxygen concentration in the reaction mixture
25 increased to 5 ppm and was kept at < 5 ppm by lowering the rotational speed of the stirrer. After 16 minutes 225 mmoles of NaOH had been added, and the reaction came virtually to a stop. The reaction mixture was then heated at 80°C for 15 minutes with light stirring, after which, at the same temperature, the product solution was removed through a filter
30 candle. By adding 90.1 g of fresh starch hydrolysate dissolved in 400 g of

water immediately a further cycle was carried out with the same catalyst, the reaction time now being 18 minutes. A corresponding 3rd cycle lasted 17 minutes. According to ^{13}C NMR, the products contained as main component sodium maltobionate. The metal concentration was $<0,1$ ppm for Bi and <1 ppm for Pd.

Example 8

The process of Example 7 was carried out, except that heating of the reaction mixture to 80°C at the end of the reaction was omitted. With this procedure the reaction time increased to 30 minutes in the 2nd cycle and to 75 minutes in the 3rd cycle, i.e., the catalyst activity was reduced very sharply.

Example 9

The process of Example 2 was repeated, except that the reaction temperature was 50°C and instead of caustic soda triethyl amine was used as base. The oxygen concentration was adjusted so as not to exceed a concentration of 4 ppm. After a reaction period of 30 minutes the theoretical amount of triethyl amine had been added and the reaction came virtually to a stop. In this way, after the catalyst was filtered off, an aqueous solution of the triethyl ammonium salt of lactobionic acid was obtained (analysis by means of ^{13}C NMR).

Example 10

The process of Example 9 was repeated, except that instead of triethyl amine calcium hydroxide was added as base in the form of a 20% aqueous suspension. The oxygen concentration in this experiment was restricted to

a maximum of 10 ppm. The reaction was complete after 70 minutes, and after filtration and drying of the resulting solution 99 g of calcium lactobionate were obtained as beige-colored solid matter (analysis by means of ^{13}C NMR).

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Example 11

The process of Example 2 was repeated, except that instead of lactose were used 0.25 mole of cellobiose. The reaction period was 20 minutes. In this way the sodium salt of cellobionic acid was obtained. The conversion to a highly pure product was practically complete.

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Example 12

As described in Example 2, instead of lactose were used 100 g of a starch hydrolysate (composition: 5% glucose, 11% maltose, 14% triose, 8% tetrose, 10% pentose, 5% hexose, 25% heptose, 21% higher sugars), dissolved in 233 g water. The reaction was carried out at 50°C. At a caustic soda addition of 87 mmol the oxygen concentration in the reaction mixture increased and was kept at <10 ppm by regulating the speed of the stirrer. After 50 min 115 mmoles of NaOH had been added, and the reaction came virtually to a stop. The reaction mixture was then heated at 80°C for 15 minutes with light stirring, after which, at the same temperature, the product solution was removed through a filter candle. By adding 100 g of fresh starch hydrolysate dissolved in 233 g of water a further cycle was carried out with the same catalyst, the reaction time now being also 55 min. According to the ^{13}C NMR, the products contained a mixture of polyhydroxycarboxylic acids, derived from the used oligosaccharides.

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Claims

1. A process for preparing polyhydroxycarboxylic acids by the selective oxidation of di-, tri-, oligo- and polysaccharides in an alkaline medium using an oxygenous gas in the presence of Pd on a carrier as catalyst and Bi as promoter, characterized in that at a Pd concentration in the reaction mixture of at least 40 mg/l and a molar ratio of Bi to Pd in the range of from 1:5 to 1:40, in which process towards the end of the reaction, as soon as a strong increase is observed in the oxygen concentration in the liquid phase, the oxygen supply is reduced until its concentration in the liquid phase is not more than 20 ppm.
2. A process according to claim 1, characterized in that a reduction of the supply of oxygen ensures that the oxygen concentration in the liquid phase does not exceed 10 ppm.
3. A process according to claim 1, characterized in that a reduction of the supply of oxygen ensures that the oxygen concentration in the liquid phase does not exceed 5 ppm.
4. A process according to claim 1, characterized in that a reduction of the supply of oxygen ensures that the oxygen concentration in the liquid phase does not exceed 1 ppm.
5. A process according to claim 1, characterized in that for the polysaccharide use is made of maltose or lactose.
6. A process according to claim 1, characterized in that the oxygen supply in the reaction mixture is reduced by lowering the stirring speed of the agitator in the reactor.

7. A process according to claim 1, characterized in that the oxygen reduction in the reaction mixture is effected by diluting the oxygen gas passed into the reactor with an inert gas, e.g., nitrogen.
- 5
8. A process according to claim 1, characterized in that the Bi is separately incorporated into the reaction mixture prior to the start of the reaction.
- 10
9. A process according to claim 1, characterized in that the [Pd] is at least 100 mg/l and the [Bi] is at least 20 mg/l.
10. A process according to claim 1, characterized in that the reaction is carried out at a temperature in the range of 30° to 70°C.
- 15
11. A process according to claim 10, characterized in that the reaction is carried out at a temperature in the range of 40° to 55°C.
12. A process according to claim 1, characterized in that the Bi is added in the form of a water-soluble salt.
- 20
13. A process according to claim 1, characterized in that the reaction is carried out at an initial polysaccharide concentration in the range of 10 to 55 wt.%.
- 25
14. A process according to claim 13, characterized in that the polysaccharide concentration is in the range of 15 to 35 wt.%.
15. A process according to claim 1, wherein for several oxidation cycles use is made of the same catalyst that is obtained after filtration of the
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reaction mixture, characterized in that on conclusion of the reaction the reaction mixture is heated at a temperature in the range of 50° to 90°C.

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INTERNATIONAL SEARCH REPORT

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Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	FR 2 417 489 A (MERCK PATENT G.M.B.H.) 14 September 1979 see page 4, line 21 - line 35 see page 6, line 2 - line 7 see claim 1	1
Y	--- EP 0 151 498 A (AKZO N.V.) 14 August 1985 see page 4, line 21 - line 28 see claim 1	1
Y	--- DE 38 23 301 C (DEGUSSA AG) 2 November 1989 see page 3, line 15 - line 24 see claim 1 -----	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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